Method for Nondestructive Evaluation of Thermal Protection System Materials and Other Materials via Ultraviolet Spectroscopy

presented by
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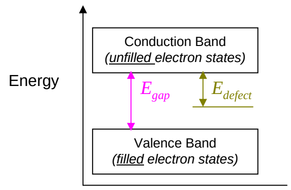
UV Spectroscopy Fundamentals

Inorganic Compounds



Excitation of states from:

Valence → Conduction Band

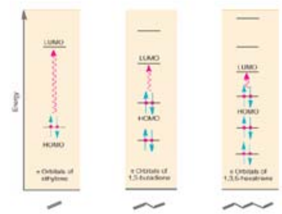
Defect → Conduction Band

by absorbing light with

$E = E_{gap}$ or E_{defect}

EXAMPLES: *Super Light Ablator (SLA)*
Thermal Coatings

Organic Compounds



Excitation of states from:

Highest Occupied →
Lowest Unoccupied Molecular Orbital
(HOMO → LUMO)

by absorbing light with

$E = E_{HOMO} - E_{LUMO}$

EXAMPLES: *PICA*
Cyanate Esters, Epoxides

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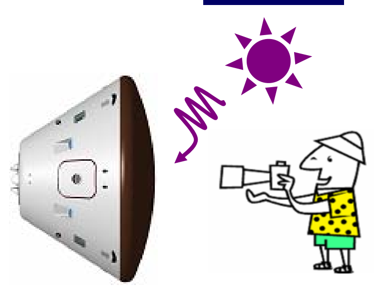
Technology Overview

Description of Technology

UV Source



Sample of Interest

Imaging System, Spectrometer, & Eager Scientist

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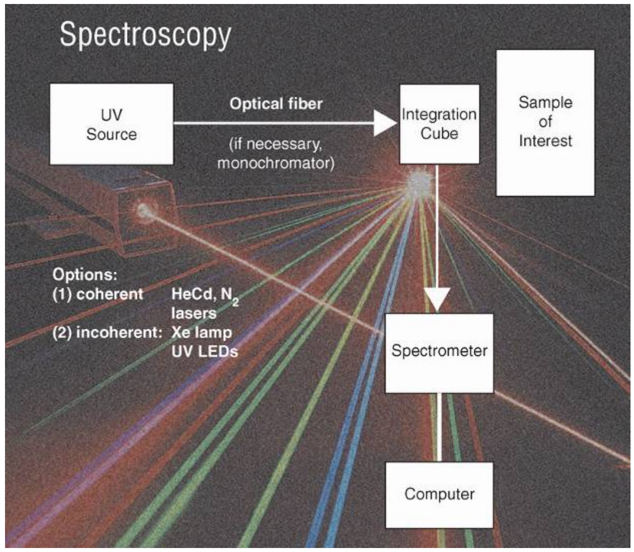
Technology Schematic



Applications

- Manufacturing process development, quality control, material aging/health issues
- Space
  - Inspection of composite and resin-based structures (TPS)
- Aerospace
  - Real-time process control of a composite structure's initial curing
- Commercial Structures
  - Composite Structures: Bridges, chemical storage tanks
  - Paints and coatings
- Medical/Dental Structures
  - Determination of end-cure point of resin fillings

Benefits

- **Nondestructive**
  - Materials not damaged or destroyed
- **Lightweight, highly portable**
  - *In-situ* measurement capabilities
  - Eliminates disassembly, destructively obtaining small samples for lab testing
- **Cost-effective**
  - Hardware widely used in UV imaging, spectroscopy

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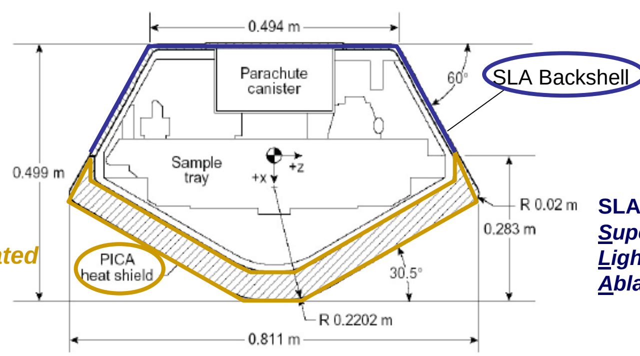
Test-Bed System: *Stardust*

PICA:
***P**henolic*
***I**mpregnated*
***C**arbon*
***A**blator*



SLA:
***S**uper*
***L**ight*
***A**blator*

Can UV imaging and spectroscopy be used to identify:
- *Structural variations?*
- *Chemical composition variations?*

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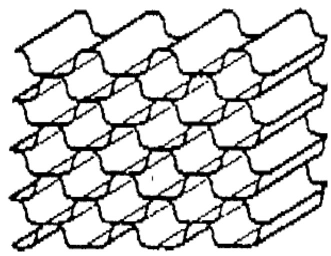
SLA Backshell

Thermal Protection System Material – SLA
Super Light Ablator

Composition:
Ground cork + silicon + phenolic microspheres in a silicone binder packed into a phenolic honeycomb

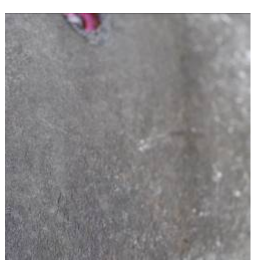
Response to Ultraviolet Light:
1. Organic: Phenolic resin
2. Inorganics: Visible defect states associated with Si
(red + blue + green → white light)



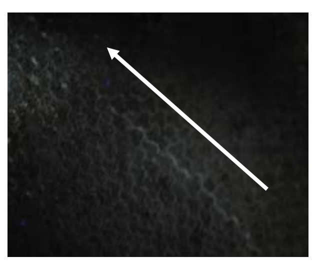
SLA Backshell

Imaging Response at Bond Line:

Visible Illumination
(room lighting)



Ultraviolet Illumination
(λ_{Excite} = 337 nm)



UV Illumination Shows SLA Excess at Mating Surfaces of Honeycomb

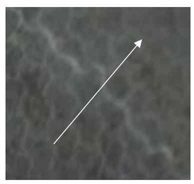
Post-Manufacturing Inspection of Seam Variations

Test-Bed Systems: Stardust

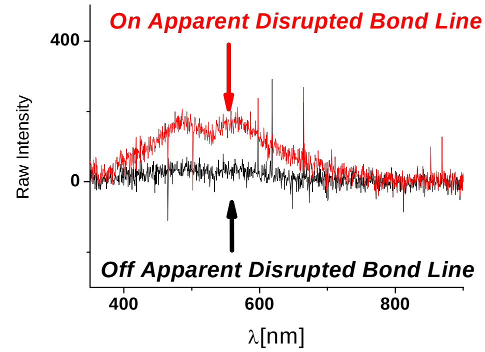
SLA Backshell

Spectral Response at Bond Line:

Perform UV spectroscopy on and off bond line



λ_{Excite}= *337 nm*



UV Spectroscopy shows Si-based defect response

Capability to Pinpoint Source of Post-Manufacturing Variation

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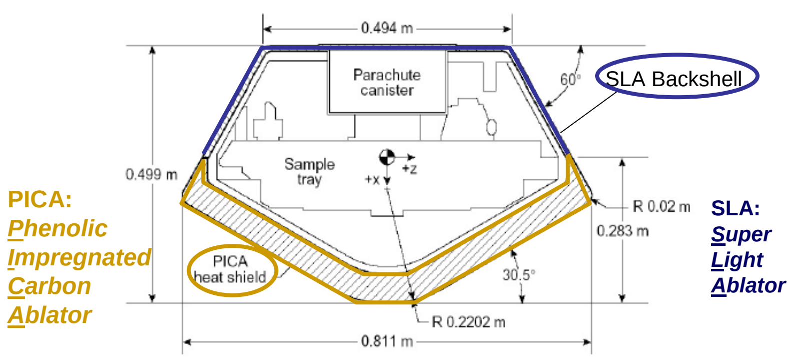
Test-Bed System: *Stardust*



Can UV imaging/spectroscopy be used to identify:
- *Structural variations?*
- *Chemical composition variations?*

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Test-Bed Systems: Stardust

Forebody Heatshield

Thermal Protection System Material – PICA

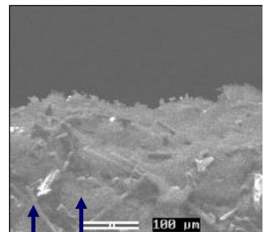
Phenolic Impregnated Carbon Ablator

Composition:

Carbon fiber form impregnated with phenolic resin and cured

Response to Ultraviolet Light:

Organic: associated with π electron transition in functional groups of phenolic resin



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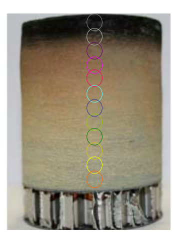
Test-Bed Systems: Stardust

Forebody Heatshield

How can we determine chemical composition variations across a material ?



Conduct ultraviolet spectroscopy

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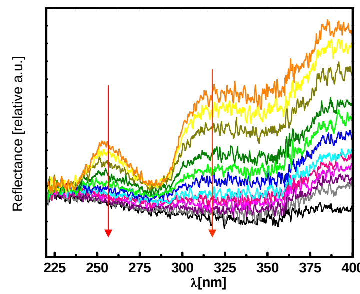
Forebody Heatshield

Probe reflectance vs. length:

(chemical composition variation vs. length is a result of thermal exposure of the PICA)



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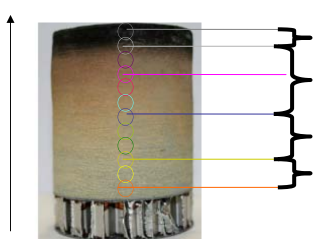
<u>*Test-Bed Systems: Stardust*</u>

Forebody Heatshield

Changes in spectra correspond to changes of chemical functional groups:

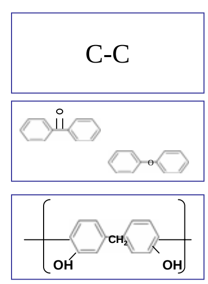


Condensed PAHs & singly bonded carbon (out of instrumental range)

Increased methyl groups and loss of ethers, loss of benzenoid groups

Dehydration of –OH on phenyl groups to form diphenyl/diphenylene ethers, hydroxybenzophenone

(Biphenyl)$_n$



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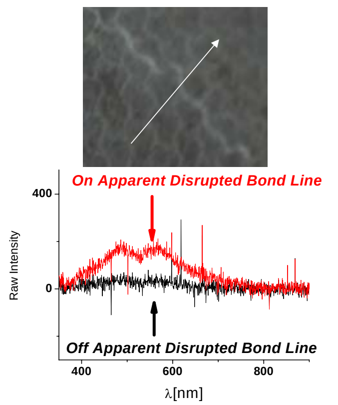
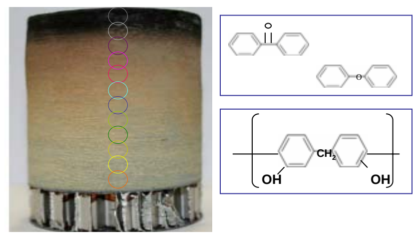
Test-Bed System Summary

UV imaging/spectroscopy can be used to identify:
- *Structural variations*
- *Chemical composition variations*





Extended Developmental Efforts:
Chemical Composition Variation Associated with Degree of Cure

Technology Transfer

Currently seeking patent protection
- *Licensing opportunities available*

Partnership/Collaboration opportunities: Scale-up
- *Development of large-scale scanners*
- *Materials database expansion*

For more information:
http://ipp.gsfc.nasa.gov/ft-tech-materials-testing.html

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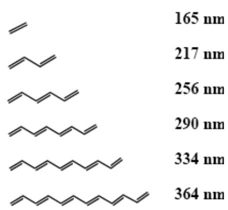
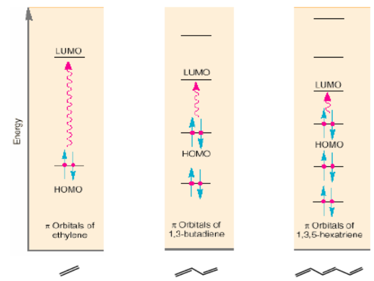
Effect of Conjugation on Absorption Peak Position

- Linear carbon chains

As the amount of conjugation (double-single bonds) increases, the peak position of the UV spectrum red shifts:



Red shifting is a consequence of the change in the electronic states (energy levels):



Effect of Conjugation on Absorption Peak Position

- Benzene Rings/Polycyclic Aromatic Hydrocarbons (PAH)
  - Similar to the linear chains, when PAH present, the peak in the absorption spectrum shifts as the number of rings in the PAH increases